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STRENGTH PROPERTIES OF REINFORCED PLASTIC LAMINATES AT ELEVATED TEMPERATURES

(EPOXY RESIN ERSB-0111 AND 181-A1100 GLASS FABRIC)

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FOREWORD

This report was prepared by the Forest Products Laboratory. Work here reported was sponsored by the AF Materials Laboratory under USAF Contract No. DO 33(657)63-358. This contract is carried under Project No. 7381, "Materials Application," Task No. 738103, "Materials Information Development, Collection and Processing." It was administered under the direction of the AF Materials Laboratory Research and Technology Division, Mr. T. J. Reinhart, Jr., project engineer.

Data on the epoxy laminates are based on work that was done between August 1962 and August 1963.

The material tested may not have been developed or intended by the manufacturer for the conditions to which it was subjected. Performance is therefore not necessarily indicative of its utility under less stringent conditions or for other applications.

ABSTRACT

Several reinforced plastic laminates that show promise of having good strength properties at elevated temperature are being evaluated to determine their strength and elastic properties. Flexure, tension, compression, interlaminar shear, and bearing tests parallel to the warp direction are made to determine the effects of high temperature and duration of exposure on the strength properties. Tension tests at 45° to the warp direction are made to obtain data from which edgewise shear strength can be calculated. Creep and stress-rupture data are obtained under both tension and compression loads. In addition to strength properties, data are obtained on weight loss of the laminated material during exposure.

This report is the eighth in a series that present strength properties of materials designed to endure elevated temperatures. Data have been presented on such laminated materials as silicone-glass, phenolic-glass, silicone-asbestos, phenolic-asbestos, epoxy-glass, and phenyl-silane-glass. This report presents strength properties and strength-exposure curves of an epoxy resin laminate, made by Union Carbide Plastics Company, having a special blend of resin labeled ERSB-0111 in conjunction with 181-A1100 glass fabric. Data are presented in both tables and curves. The data show the effects of temperature between 80° and 1,000° F., and exposure periods between 0.05 and 1,000 hours on the individual strength properties. The magnitude of the various effects may be judged separately. In general, the data show that all mechanical strengths, except tension at 0°, decrease uniformly with increases in temperatures of short duration. The tensile strength remained relatively high until a critical exposure was reached and then dropped rapidly. The data also show that the strengths remain relatively constant during most constant temperature exposures until a critical exposure is reached and then drop rapidly.

This technical documentary report has been reviewed and is approved.

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I. INTRODUCTION

This presentation of data is the eighth in a series of reports to present design criteria at elevated temperatures for plastic laminates that are currently available commercially. Previous reports are listed under "References" at the end of this report.

In general, the development of ever faster flight vehicles and the resulting increases in their operating temperatures require expansion of knowledge concerning the strength properties of the new structural materials to be used. Reinforced plastic laminates are being used or considered in many structural components of flight vehicles, and research is being directed toward the development of combinations of resins and reinforcements that have a high degree of heat resistance. Standard design data are needed for heat-resistant plastic materials to show the effects of elevated temperatures, for various periods of exposure, on their strength and related properties. In order to provide such design data for currently available plastics over their useful temperature range, the Forest Products Laboratory is engaged in a program of research and evaluation, in cooperation with RTD and materials manufacturers.

The scope of the program includes the evaluation of the effect of the following:

(A) Time and temperature on the deterioration of plastics, as measured by weight loss.

(B) Duration of exposure in an unstressed state at elevated temperatures on the mechanical properties in flexure, tension, compression, bearing, and shear (both interlaminar and edgewise).

(C) Duration of exposure at constant tensile and compressive loads at elevated temperatures on strength and deformation.

The current temperature range referred to in this report is from room temperature to 1,000° F. (27° to 538° C.), and the duration of exposure (soak period) is from a few minutes to 1,000 hours.

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II. MATERIAL

Laminated panels of epoxy resin reinforced with glass fabric were furnished by the Union Carbide Plastics Company, Bound Brook, N.J. Information supplied with this material is as follows:

Resin--ERSB-0111

Catalyst--1-1/2 percent BF_3 monoethylamine on resin solids

Fabric orientation--Not nested but parallel laminated

Number of plies--12

Fabric--"E" glass, 181 and A1100 finish

Resin content--37 percent, impregnated from solution

Precure--None

Cauls--Polished steel with silicone release agent

Cure--1 hour at 160° C. (320° F.) and 100 pounds per square inch, then 2 hours at 190° C. (374° F.)

Postcure--6 hours at 205° C. (401° F.)

Union Carbide furnished 25 panels 1/8 inch thick and 22 inches square. The Forest Products Laboratory determined the average specific gravity to be 1.82, the average Barcol hardness to be 73, and the resin content from burnoff tests to be 36 percent.

III. TEST METHODS

Each mechanical test was made in accordance with generally accepted engineering practices, summarized as follows:

Mechanical Test	Federal Standard 406 Test Method Number	ASTM Method
Flexure	1031	D 790-49T
Tension	1011	D 638-60T
Compression	1021	D 695-63T
Interlaminar Shear	1042 (clamped)	None[1]
Bearing	1051	D 953-54 (Method A)
Tensile stress-rupture	1063	None
Compressive stress-rupture	None	None
Weight loss	7041	None

The test methods used in this study are described in these references, and the apparatus used are described in the appendix of ASD Technical Report 61-482 (5).[2]

IV. PRESENTATION OF DATA

Table 1 presents the results of preliminary quality tests of these laminates. The specimens were cut and tested so that the fiber stress was applied parallel to the warp direction of the fabric. Flexure specimens were 1/8 inch thick by 1 inch wide by 4 inches long, and compression specimens were 1/8 inch thick by 3/4 inch wide by 3-1/8 inches long with a 1/2-inch-wide net section. Compression specimens were laterally supported and loaded at a rate of head motion of 0.007 inch per minute, so that load-deformation data could be obtained. Each value shown for flexure and compression is the average of five specimens.

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[1] However, the Aircraft Research Technical Committee has a method No. 11 that was used.

[2] Underlined numbers in parentheses refer to literature listed under "References" at the end of this report.

Tables 2 through 9 present the results of tests to determine the effects of different elevated temperatures for various periods of exposure on properties of this material. Strength properties shown for each specific temperature are based on tests of specimens that were both soaked and tested at that temperature. All data, except in Tables 4 and 7, indicate properties after exposure of specimens in the unstressed state. Tables 4 and 7 present stress-rupture and creep data that were obtained from specimens exposed in the stressed state. After some of the unstressed soak periods, strength properties could not be measured or were zero. Unless otherwise noted, each value in the tables, except in Tables 4 and 7, is the average of five specimens. Values in Tables 4 and 7 are from individual specimens unless otherwise noted.

Figures 1 through 17 show the effects of soak periods at elevated temperatures on the various properties. Data were plotted from the tables. Smooth curves have been drawn to approximate the plotted points. The symbol < , meaning less than, is used in conjunction with the plotted points at zero strength. Data so indicated are from specimens that had become so weakened that they fell apart during handling at the indicated exposure period. Obviously, the strength or stiffness was nil at some soak period less than that indicated but the exact time of zero strength is unknown.

The relative amount of creep at various stress levels for three temperatures is shown in Figures 8 and 13, based on data in Tables 4 and 7. At each stress level, a short horizontal line shows the creep that occurred from the time of initial loading until the specimen failed or was removed from the creep machine. The creep line at individual stress levels is shown beginning at an "average" stress-strain curve obtained from strength tests loaded to failure in about 3 minutes, and ending when the specimen failed or the test terminated at 1,000 hours.

Figures 16 and 17 present curves that summarize the effect of temperature on five mechanical properties after exposure for 1/2 and 100 hours. All strengths are shown as percentages of their respective room-temperature values. The curves are based on values from other strength-time plots in this report.

V. DISCUSSION OF RESULTS

Preliminary quality tests (Table 1) of this epoxy resin laminate reinforced with 181-A1100 glass fabric showed results that were generally in agreement with MIL-R-9300A requirements. On the basis of this sampling, the following comprehensive evaluation was made:

Weight Loss

Deterioration due to continued exposure to elevated temperatures was measured through the loss of weight by the flexure specimens during their respective exposure periods (Table 2). Weights retained are shown as percent of initial weight in Figure 1 for various temperatures and periods of exposure at these elevated temperatures. The data show that at 300° and 400° F. for exposures of from 1/6 hour to 1,000 hours, the specimens lost from 1 to 6 percent of their weight. Increases in temperature above 400° F., which was the postcure temperature, reduced weight retention at all periods of exposure and, of course, there was further reduction in weight retention with increases in duration of exposure. Rapid weight losses were experienced above 400° F. It appears as though rapid losses occurred at temperature and exposure conditions that cause losses greater than 10 percent.

Flexure Test Results

The results of flexure tests, as presented in Table 2 and Figures 2, 3, and 4, show the effect of time and temperature on the modulus of rupture and the modulus of elasticity, and the effect of weight loss on strength at various temperatures and periods of exposure. At constant temperatures of 300° and 400° F., the strength-exposure curves (Fig. 2) show strength losses with the first application of heat (0.17 hour duration), and then increase in strength with increases in duration of exposure until a maximum is reached. At constant temperatures of 500° to 700° F., the strength dropped rapidly in the first 1/6 hour, remained relatively constant for various periods, and then dropped to zero. At temperatures above 700° F., all strength is lost within 1 hour of exposure. The flexural modulus of elasticity at various exposures (Fig. 3) has about the same pattern as that for modulus of rupture.

Since weight loss determinations in this series of tests were made on flexure specimens, the data could provide a direct comparison of flexural strength with weight loss. Such a comparison was attempted in Figure 4. The envelope of values, that usually converges to zero at some resin content, is not well defined because the values at 600° F. have a wide range. However, a trend does exist which shows that high strengths occur when weight loss is small and vice versa.

Tension Test Results

The results of tension tests, presented in Tables 3, 4, and 5 and Figures 5 through 9, show the effects of exposure on several properties.

The results of tension tests at 0° to warp (Tables 3 and 4 and Figs. 5, 6, 7, and 8) show the detrimental effects of time and temperature on strength and elongation in a direction of loading where the glass fibers play a major role. Figure 5, for example, shows relative strength values higher than those shown for flexure (Fig. 2). Rapid heating to 700° F., with only 0.05 hour soak, causes strength reductions of less than 20 percent of the control strength. Strength-exposure curves (Fig. 5) show nearly constant values for temperatures from 300° to 800° F. for a range in time of exposure. The strength level of this plateau is greater than 80 percent of the control strength, and the extent of the plateau at temperatures between 400° and 700° F. depends upon the time of exposure. During periods of exposure beyond the limits of the plateau, the strength declines rapidly. Some tensile strength is available for short periods of exposure up to 1,000° F., whereas other mechanical strengths, that will be shown later, are nil at temperatures above 700° F. The tensile modulus of elasticity (Fig. 6) is also nearly a constant value between 2-3/4 and 3 million pounds per square inch at temperatures of 300°, 400°, and 500° F., except after 100 hours at 500° F. Temperatures above this exposure cause modulus values to be about 2 million pounds per square inch up to the time rapid degradation occurs.

The results of tension tests at 45° to warp (Fig. 9) show the detrimental effects of time and temperature on strength in a direction of loading where shear stresses between fibers in the resin provide resistance to the tensile force. In this direction of loading, the detrimental effect of time and temperature is greater than that at 0° tensile loading (Fig. 5), and about equal to that in flexure (Fig. 2). It can be shown that the edgewise shear strength is related to the tensile properties at 0° and 45° to the warp (5). Hence the effects of exposure shown by the 0° and 45° data are applicable to the effect of exposure on edgewise shear properties.

The results of tension tests at constant loads (Table 5, Figs. 7 and 8) show the effect of stress, temperature, and time on strength and creep. The effects of temperature and time previously discussed were obtained on unstressed specimens that were loaded to failure after exposure, but the creep and stress-rupture tests provided data on specimens that were loaded to a constant stress during exposure. Creep specimens tested at elevated temperatures were heated at their respective temperatures for 1/2 hour before constant load was applied.

A comparison of the strength data obtained as a result of exposure in the unstressed as well as in the stressed condition is shown for three temperatures in Figure 7. The stress-rupture data are represented by solid lines and the data for unstressed material, i.e. strength-exposure curves, by broken lines--the latter being transferred from Figure 5. The stress-rupture values at each temperature of exposure are lower, as expected, than the strength-exposure curves.

In analyzing the stress-rupture data at elevated temperatures, the tensile strength of unstressed material must be taken into account, noting that the strength first decreased with application of heat and then increased with increases in exposure until degradation occurred. This phenomena causes the 300° and 500° F. stress-rupture curves to be flatter than the room temperature stress-rupture curve during the first two log-cycles of their length. When detrimental thermal degradation occurs, the curves decline rapidly. The decrease parallels the strength-exposure curve at the same temperature, but the decrease occurs after a shorter period of exposure, so that at equivalent stresses the duration of exposure is less for stressed specimens than for unstressed specimens.

Strain data were also observed during the stress-rupture tests. Strains observed at full load were about the same as those observed at the same stress when the material was loaded in the short-time tension test after 1/2-hour exposure to temperature. To eliminate unmeasured strains resulting from the heating and the original alignment of fixtures, only the creep data are presented in Table 4 and in Figure 8. In Figure 8, these creep values have been added to the average stress-strain curve for the material. The length of the creep lines in Figure 8 shows that at room temperature there is very little creep, but as the temperature increases to 500° F., the amount of creep increases considerably.

Compression Test Results

The results of the compression tests, which were obtained by loading parallel to the warp direction of the laminate, are presented in Tables 6 and 7 and Figures 10 to 13. These data show the effects of exposure on specimens in both the stressed and unstressed condition. Figures 10 and 11 show the compressive strength and modulus of elasticity of specimens after exposure to various temperatures for various soak periods in the unstressed condition. Rapid heating and soaking for only the duration of the load causes an initial drop in strength at all temperatures. After this initial soak period of only 0.05 hour, the strength-exposure curve at 300° F. increases with increases in time, but the curves at other temperatures remain constant with time until permanent degradation occurs.

Figure 12 shows the effect of exposure on compressive strength in the stressed condition. The stress-rupture data in this figure are compared with the strength-exposure data. These stress-rupture curves are lower for each temperature than its respective strength-exposure curve, as was observed with tensile characteristics. The slope of the room temperature stress-rupture curve is greater than that for the 300° or 500° F. curves. At 300° F., the strength-exposure curves show a strengthening with exposure, and at the same time degradation due to stress-rupture fatigue is occurring, so that the stress-rupture curve has little slope.

Strain data were also observed during the stress-rupture tests. Strains observed at full load were about the same as those observed at the same stress when the material was loaded in the short-time compressive test after 1/2-hour soak. To eliminate unmeasured strains during heating and alignment of fixtures, only the creep is presented in Table 7 and Figure 13. These creep values, shown in Figure 13, have been added to the average stress-strain curve for the material.

Interlaminar Shear Tests (Table 8)

The tests for interlaminar shear strength show the effects of time and temperature in a plane where the reinforcing fibers play a minor role. In this test the resin strength predominates. Figure 14 shows a fairly uniform drop in strength at 1/2-hour exposure for increases in temperature to 700° F. Subsequent increase in soaking period at constant temperature does not have as great an affect.

Maximum Bearing Stress

The tests for maximum bearing stress that this material will sustain after exposure show the effects on a mechanical property that is a combination of tensile, compressive, and shear strengths. The results (Table 9), however, do not indicate the effects to be cumulative. The magnitude and pattern of the strength-exposure curves (Fig. 15) is similar to that exhibited by the other mechanical tests.

VI. SUMMARY OF RESULTS

In general, the exposure of the glass-reinforced plastic laminates to elevated temperatures less than 1,000° F. eventually reduces the strength to zero. The data and curves indicate the strength available for use at various temperatures and soak periods.

The amount of available strength varies with the property evaluated, period of exposure, and temperature of exposure. Available strengths are summarized for five mechanical tests after 1/2 and 100 hours of exposure in Figures 16 and 17. The curves in Figure 16 show that tensile strength in excess of 75 percent of room temperature value is available through 700° F., whereas all other strengths are almost nil at 700° F., -- the latter having decreased uniformly from room temperature. Figure 17 shows the strengths retained after 100 hours. The pattern of tensile strength has changed considerably, but others have not changed as much.

In general, the test data and curves presented in this report show that strength drops with the first application of heat. The tensile strength was affected the least and the compressive strength the most. After the first strength loss, the material was relatively stable with increasing soak time until permanent deterioration occurred.

REFERENCES

The following previous reports have been prepared in this series:

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2. ______
1960. Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (Phenolic-Asbestos, R/M Pyrotex Felt Style 41-RPD). WADD 60-177, Part 1.

3. ______
1960. Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (Epon 1031 Resin and 181-Volan A Glass Fabric). WADD TR 60-466.

4. ______
1961. Tensile and Compressive Strength of Reinforced Plastic Laminates After Rapid Heating. WADD TR 60-804.

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1962. Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (CTL 37-9X Resin and 181-A1100 Glass Fabric). ASD TR 61-482.

6. ______
1962. Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (Silicone-Asbestos, R/M Pyrotex Felt Style 45-RPD). ASD-TDR-62-406.

7. ______
1962. Effect of Elevated Temperatures on Strength Properties of Reinforced Plastic Laminates. ASD-TDR-62-629.

8. ______
1963. Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (Narmco 534 Resin and 181-A1100 Glass Fabric). Report submitted to ASD Sept. 1963.

9. ______, and Kimball, K. E.
1959. Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (DC 2106 Resin and 181-Heat Cleaned Glass Fabric). WADC TR 59-229.

TABLE 1.--RESULTS OF PRELIMINARY QUALITY TESTS OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC

	Flexure			Compression		
	Modulus of elasticity	Fiber stress at proportional limit	Modulus of rupture	Modulus of elasticity	Stress at proportional limit	Maximum stress
	Million p.s.i.	1,000 p.s.i.	1,000 p.s.i.	Million p.s.i.	1,000 p.s.i.	1,000 p.s.i.
TESTED AT ROOM TEMPERATURE						
Average of 5	3.04	37.9	74.8	3.16	29.6	51.6
Standard deviation	.05	4.1	3.0	.06	4.6	1.7
MIL-R-9300A	3.20	....	70.0	....	....	50.0
TESTED AT 500° F. AFTER 0.5 HOUR AT 500° F.						
Average of 5	2.10	10.6	18.8	2.29	7.7	12.2
Standard deviation	.03	.6	.8	.12	1.1	.6
MIL-R-9300A	2.00	....	22.0	....	....	10.0
TESTED AT 500° F. AFTER 192 HOURS AT 500° F.						
Average of 5	2.44	18.5	40.8	2.79	8.8	16.9
Standard deviation	.12	.9	8.3	.12	1.1	1.4
MIL-R-9300A	1.80	....	18.0	....	....	....

TABLE 2.--FLEXURAL PROPERTIES OF EPOXY LAMINATES MADE OF
ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC

Temperature	Duration of exposure	Modulus of elasticity: Value	Modulus of elasticity: Coefficient of variation	Stress at proportional limit: Value	Stress at proportional limit: Coefficient of variation	Modulus of rupture: Stress	Modulus of rupture: Coefficient of variation	Modulus of rupture: Percentage of room temperature stress	Weight loss
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
°F.	Hours	Million p.s.i.	Percent	1,000 p.s.i.	Percent	1,000 p.s.i.	Percent	Percent	Percent
Room	....	3.50	1.8	51.9	11.8	89.2	2.4	100.0	....
300	.17	3.25	3.8	27.7	5.7	49.4	6.2	55.4	.79
	.5	3.28	2.5	27.4	14.2	52.5	5.3	58.8	.70
	7	3.46	1.2	27.4	12.0	66.2	1.2	74.2	.43
	96	3.41	4.5	30.8	11.5	65.7	3.2	73.6	3.94
	1,000	3.40	3.0	27.1	7.8	66.6	1.7	74.7	4.07
400	.17	2.94	1.7	19.2	10.0	32.8	4.4	36.8	1.89
	2	3.01	1.5	23.7	4.6	39.8	6.9	44.6	3.73
	24	3.23	1.1	26.3	5.3	45.4	4.9	50.9	4.97
	240	3.25	2.5	23.4	8.4	40.9	3.0	45.8	3.73
	1,000	3.03	5.5	17.5	26.8	30.2	17.0	33.8	6.28
500	.17	2.47	7.7	12.7	26.0	19.7	8.0	22.1	4.34
	.5	2.58	4.1	15.0	5.7	21.6	4.8	24.2	5.60
	7	2.58	1.1	12.3	13.6	18.5	4.4	20.7	8.03
	96	2.54	2.4	10.7	11.6	18.0	4.2	20.2	4.60
	1,000	....	....	......	....	......	....	....	19.80
600	.17	1.81	7.5	6.2	17.0	11.3	12.1	12.7	1.15
	2	1.81	12.0	7.0	5.9	11.0	8.3	12.3	2.41
	24	2.12	12.1	8.0	12.8	13.6	9.2	15.2	8.00
	240	....	....	......	....	......	....	....	25.55
	1,000	....	....	......	....	......	....	....	[1]34.80
700	.17	1.01	25.6	2.8	21.7	5.0	10.1	5.6	4.86
	.5	1.05	8.0	2.8	9.4	4.8	6.2	5.4	7.54
	7	2.35	4.4	7.3	6.0	17.6	9.4	19.7	9.72
	96	....	....	......	....	......	....	....	[1]34.80
800	.17	1.20	22.4	4.1	21.4	10.7	16.3	12.0	13.30
	2	....	....	......	....	......	....	....	21.86
	24	....	....	......	....	......	....	....	[1]34.80
900	.17	1.51	31.6	2.7	19.0	6.7	18.4	7.5	18.44
	.5	....	....	......	....	......	....	....	34.80

[1]Resin content at 900° F. after 0.5 hour exposure.

TABLE 3.--TENSILE PROPERTIES OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC. TESTS MADE PARALLEL TO WARP DIRECTION.

Temperature	Duration of exposure	Modulus of elasticity		Stress at proportional limit		Maximum stress			Strain at maximum stress
		Value	Coefficient of variation	Value	Coefficient of variation	Value	Coefficient of variation	Percentage of room temperature value	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
°F.	Hours	Million p.s.i.	Percent	1,000 p.s.i.	Percent	1,000 p.s.i.	Percent	Percent	Inch per inch x 100
Room	....	2.99	2.6	30.5	8.3	67.5	3.3	100.0	2.40
300	.05	2.94	2.2	21.9	10.2	58.7	3.0	87.0	2.16
	.5	2.95	1.5	31.9	8.6	63.6	3.3	94.2	2.30
	7	3.05	5.2	24.8	14.5	63.9	2.6	94.7	2.35
	96	3.00	1.4	23.1	11.2	64.8	2.6	96.0	2.41
	1,000	2.93	3.8	26.0	11.0	61.9	6.2	91.7	2.30
400	.05	2.84	5.4	22.8	3.7	56.0	4.9	83.0	2.34
	.5	2.85	5.2	23.4	8.2	57.2	4.0	84.7	2.39
	7	2.88	5.2	24.7	12.9	58.6	2.7	86.8	2.44
	96	2.96	3.2	26.7	10.2	57.0	1.5	84.4	2.25
	1,000	2.88	3.6	15.5	11.3	25.1	15.0	37.2	1.03
500	.05	2.83	5.7	16.7	8.7	59.0	4.3	87.4	2.63
	.5	2.87	3.0	18.2	19.5	58.8	3.7	87.1	2.59
	7	2.76	2.3	17.2	7.0	56.7	2.4	84.0	2.66
	96	2.77	5.4	17.4	14.7	50.9	3.6	75.4	2.38
	1,000	....	....	......	....	7.2	4.5	10.7	.....
600	.05	2.26	5.6	34.9	6.0	60.1	3.5	89.0	2.86
	.5	2.09	5.5	28.8	....	57.7	0.66	85.5	2.99
	2	2.23	10.0	29.8	9.3	55.4	4.5	82.1	2.68
	24	2.29	4.1	39.5	10.1	50.0	4.1	74.1	2.28
700	.05	2.12	4.5	30.4	....	57.0	5.5	84.4	3.10
	.5	2.15	8.1	33.9	13.0	51.3	5.6	76.0	2.75
	7	2.63	8.1	15.0	23.8	24.8	18.5	36.7	1.10
800	.05	2.12	7.8	27.0	....	47.0	11.0	69.6	2.57
	.5	2.22	1.4	18.9	13.2	27.8	12.5	41.2	1.61
900	.05	1.90	5.3	17.5	6.2	27.2	5.4	40.3	1.84
	.5	2.02	3.5	6.4	12.6	8.3	6.0	12.3	.45
1,000	.05	1.77	4.8	14.0	13.0	20.8	7.6	30.8	1.43
	.5	1.61	8.9	2.8	2.2	5.0	6.6	7.4	.36

TABLE 4.--STRESS-RUPTURE AND CREEP DATA FROM TENSION TESTS OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC

Applied stress	Percentage of room temperature stress	Rupture time	Creep data at-- 0.1 hour	1 hour	10 hours	100 hours	1,000 hours	Rupture
1,000 p.s.i.	Percent	Hours	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100
				ROOM TEMPERATURE				
[1]67.5	100.0	...	...	...	...	...	...	...
67.0	99.3	0.007	...	...	...	...	...	...
66.0	97.8	.025	...	...	...	...	...	0.024
65.0	96.4	.042	...	...	...	...	...	.054
62.5	92.6	.167	0.186	...	...	...	...	.198
61.0	90.4	.360	.024	...	...	...	...	.037
61.0	90.4	.10	.077	...	...	...	...	.077
60.0	88.9	1.033	.172	0.192	...	...	...	.206
57.5	85.2	3.89	.036	.063	...	...	...	.067
55.0	81.5	7.4	.043	.057	...	...	...	.108
54.0	80.0	33.45	.023	.031	0.040	...	...	.046
53.0	78.5	839.9	.026	.066	.080	0.108	...	.118
52.5	77.8	631.7	.031	.040	.048	.080	...	.125
[2]50.0	74.1	>1,000.	.023	.045	.061	.065	...	.563
				300° F.				
[1]63.6	94.2	...	...	...	...	...	...	...
60.0	88.9	.003	...	...	...	...	...	...
58.0	86.0	.009	...	...	...	...	...	...
57.5	85.2	.063	...	...	...	...	...	.110
57.0	84.5	.18	.053	...	...	...	...	.124
56.5	83.7	.42	.032	...	...	...	...	.073
56.0	83.0	3.25	.010	.020	...	...	...	.043
55.0	81.5	27.2	.007	.020	.067	...	...	.100
53.0	78.6	126.25	.008	.011	.034	.102	...	.112
50.0	74.1	100.1	.042	.051	.073	.290	...	.297
50.0	74.1	123.35	.010	.013	.047	.111	...	.148
45.0	66.7	983.0	.032	.048	.061	.147	...	.198
40.0	59.3	>1,000.0	.010	.018	.020	.069	0.073	...
				500° F.				
[1]58.82	87.2	...	...	...	...	...	...	...
58.00	86.0	.001	...	...	...	...	...	...
56.00	83.0	.004	...	...	...	...	...	...
55.50	82.2	.009	...	...	...	...	...	...
55.00	81.5	.075	...	...	...	...	...	.145
53.50	79.3	.38	.061	...	...	...	...	.100
52.50	77.8	.93	.045	...	...	...	...	.132
50.00	74.1	2.86	.061	.130	...	...	...	.599
47.50	70.4	12.62	.063	.114	.150	...	...	.578
45.00	66.7	50.75	.064	.103	.127	...	...	.435
40.00	59.3	116.6	.029	.045	.070	.200	...	.328
35.00	51.8	104.4	.028	.053	.096	.201	...	.215
25.00	37.1	143.8	.032	.049	.067	.222	...	.273

[1]Average control strength at room temperature and at 300° F. and 500° F. after 1/2 hour at temperature.

[2]After 1,000-hour duration, ultimate strength was 70,600 pounds per square inch.

TABLE 5.--TENSILE PROPERTIES[1] OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC. TESTS MADE AT 45° TO THE WARP DIRECTION

Temperature	Duration of exposure	Maximum stress		
		Value	Coefficient of variation	Percentage of room temperature value
°F.	Hours	1,000 p.s.i.	Percent	Percent
Room	....	22.1	4.1	100.0
300	.5	14.4	5.2	65.2
	96	15.8	6.2	71.5
	1,000	16.4	4.3	74.2
400	.5	9.8	6.3	44.3
	96	10.0	4.2	45.2
	1,000	5.4	46.8	24.4
500	.5	6.2	4.8	28.0
	7	5.3	2.7	24.0
	96	4.3	7.7	19.4
	1,000	0.87	11.5	3.9
600	.5	2.9	16.7	13.1
	7	1.9	15.9	8.6
	96	1.7	52.3	7.7
700	.5	1.4	21.7	6.3
	7	3.0	26.7	13.6
800	.5	1.3	10.2	5.9
900	.5	0.55	21.8	2.5

[1] The modulus of elasticity could not be determined because the load-elongation curve was concave downward from beginning to maximum load.

TABLE 6.--COMPRESSIVE PROPERTIES OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC

Temperature	Duration of exposure	Modulus of elasticity		Stress at proportional limit		Maximum stress			Strain at maximum stress
		Value	Coefficient of variation	Value	Coefficient of variation	Value	Coefficient of variation	Percentage of room temperature value	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
°F.	Hours	Million p.s.i.	Percent	1,000 p.s.i.	Percent	1,000 p.s.i.	Percent	Percent	Inch per inch x 100
Room	....	3.96	3.7	41.6	14.0	52.3	4.0	100.0	1.40
300	.05	3.27	1.6	14.3	7.7	28.5	2.1	54.5	.91
	.5	3.41	3.0	14.5	4.7	31.5	4.7	60.2	1.01
	7	3.62	2.9	13.8	7.2	34.5	4.6	66.0	1.07
	96	3.67	3.6	15.1	7.9	35.5	6.0	67.9	1.06
	1,000	3.78	3.7	17.1	4.7	34.6	6.0	66.2	1.05
400	.05	3.09	3.6	12.5	9.0	19.4	6.5	37.1	.66
	.5	3.18	3.8	11.9	4.5	22.3	4.1	42.6	.76
	7	3.06	1.2	12.7	3.6	19.7	7.5	37.7	.68
	96	3.21	3.8	13.5	5.9	23.3	3.6	44.6	.78
	1,000	3.31	3.5	13.7	8.9	21.5	1.6	41.1	.70
500	.05	2.88	1.4	6.6	10.0	12.2	2.9	23.3	.45
	.5	3.01	6.2	7.1	11.1	12.3	6.3	23.5	.44
	7	3.02	2.6	6.4	3.0	10.8	8.4	20.6	.39
	96	3.07	5.2	9.5	7.0	13.6	6.0	26.0	.47
	1,000	2.61	7.9	....	....	2.3	6.0	4.4	.....
600	.05	2.59	3.3	5.0	6.2	7.4	6.4	14.1	.32
	.5	2.44	9.2	4.4	13.8	7.4	7.6	14.1	.35
	2	2.63	2.8	5.2	8.8	7.6	5.4	14.5	.33
	24	2.68	5.4	5.9	10.3	9.0	3.4	17.2	.38
700	.05	2.06	12.9	3.0	8.9	4.3	7.9	8.2	.26
	.5	2.19	9.7	2.6	12.4	4.1	5.9	7.8	.26
	7	2.86	13.5	6.8	7.4	10.4	9.1	19.9	.40
800	.05	1.46	33.0	1.3	21.1	2.7	12.5	5.2	.30
	.5	2.42	5.1	2.7	7.4	4.5	3.5	8.6	.29
900	.05	1.79	10.8	....	....	3.0	14.8	5.7	.35
	.5	1.85	8.4	2.2	11.1	4.1	10.5	7.8	.29
1,000	.05	1.88	15.4	1.7	6.3	3.0	10.7	5.7	.33

TABLE 7.--STRESS-RUPTURE AND CREEP DATA FROM COMPRESSION TESTS OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC

Applied stress	Percentage of room temperature stress	Rupture time	Creep data at--					
			0.1 hour	1 hour	10 hours	100 hours	1,000 hours	Rupture
1,000 p.s.i.	Percent	Hours	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100
			ROOM TEMPERATURE					
[1]52.2	100.0							
54.5	104.5	0.06						0.069
54.0	103.5	.25	0.058					.073
53.0	101.5	.04						.070
51.5	98.6	2.66	.026	0.049				.068
50.0	95.8	112.1	.015	.048	0.055	0.125		.125
50.0	95.8	.3	.048					.064
49.0	93.9	.7	.040					.068
45.0	86.2	2.17	.050	.091				.144
44.0	84.3	189.4	.025	.064	.095	.132		.148
43.5	83.4	198.5	.046	.094	.102	.156		.232
40.0	76.6	724.	.011	.020	.036	.051		.066
[2]38.0	72.8	>1,000.	.030	.031	.081	.124	0.297	
37.5	71.8	>1,000.	.012	.030	.064	.073	.105	
			300° F.					
[1]31.5	60.3							
31.0	59.4	.02						.054
29.9	57.3	.07						.144
29.0	55.6	.13	.094					.097
28.5	54.6	.48	.066					.075
28.0	53.6	2.05	.034	.125				.137
27.8	53.2	3.45	.119	.173				.183
27.0	51.7	71.5	.054	.082	.115			.126
26.0	49.8	332.0	.055	.107	.137	.176		.292
25.0	47.9	893.7	.055	.092	.108	.128		.264
23.0	44.1	>1,000.	.073	.125	.139	.155	.171	
			500° F.					
[1]12.3	23.6							
12.0	23.0	.02						.026
11.8	22.6	.06						.046
11.3	21.6	.13	.062					.080
10.7	20.5	.35	.026					.060
10.5	20.1	.18	.052					.071
10.0	19.1	4.06	.032	.058				.112
9.5	18.2	6.6	.025	.057				.127
9.0	17.2	13.5	.010	.035	.065			.075
7.5	14.4	211.	.035	.053	.072	.236		.450
6.5	12.5	346.	.032	.074	.116	.200		.575
5.0	9.6	748.	.034	.078	.081	.126		.380

[1]Average control strength at room temperature and at 300° F. and 500° F. after 1/2 hour at temperature.

[2]After 1,000-hour duration, ultimate strength was 45,500 pounds per square inch.

TABLE 8.--INTERLAMINAR SHEAR STRENGTH OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC

Temperature	Duration of exposure	Maximum shear stress		
		Value	Coefficient of variation	Percentage of room temperature value
°F.	Hours	1,000 p.s.i.	Percent	Percent
Room	....	2.8	6.7	100.0
300	.5	2.3	4.3	82.1
	96	2.4	2.7	85.7
	1,000	2.3	3.2	82.1
400	.5	1.8	5.5	64.3
	96	1.7	8.7	60.7
	1,000	1.5	5.2	53.6
500	.5	.98	10.2	35.0
	7	.89	5.1	31.8
	96	.95	4.7	33.9
	1,000	.08	30.0	2.8
600	.5	.51	4.3	18.2
	7	.33	11.5	11.8
	96	.16	11.9	5.7
700	.5	.18	10.6	6.4
	7	.29	32.1	10.4
800	.5	.40	21.5	14.3
	2	.11	20.0	3.9

TABLE 9.--MAXIMUM BEARING STRESS OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-A1100 GLASS FABRIC

Temperature	Duration of exposure	Maximum bearing stress		
		Value	Coefficient of variation	Percentage of room temperature value
°F.	Hours	1,000 p.s.i.	Percent	Percent
Room	....	54.5	5.6	100.0
300	.5	38.8	5.2	71.2
	96	42.1	8.2	77.2
	1,000	44.1	4.0	80.9
400	.5	28.1	5.9	51.6
	96	35.3	14.8	64.8
	1,000	30.3	8.6	55.6
500	.5	17.3	8.6	31.7
	7	15.2	11.9	27.9
	96	15.3	10.6	28.1
	1,000	2.5	13.7	4.6
600	.5	8.0	6.4	14.7
	7	8.3	11.0	15.2
	96	3.4	21.3	6.2
700	.5	4.8	14.7	8.8
	7	7.2	16.9	13.2
800	.5	7.3	6.7	13.4
	2	3.4	36.1	6.2
900	.5	2.1	15.9	3.8

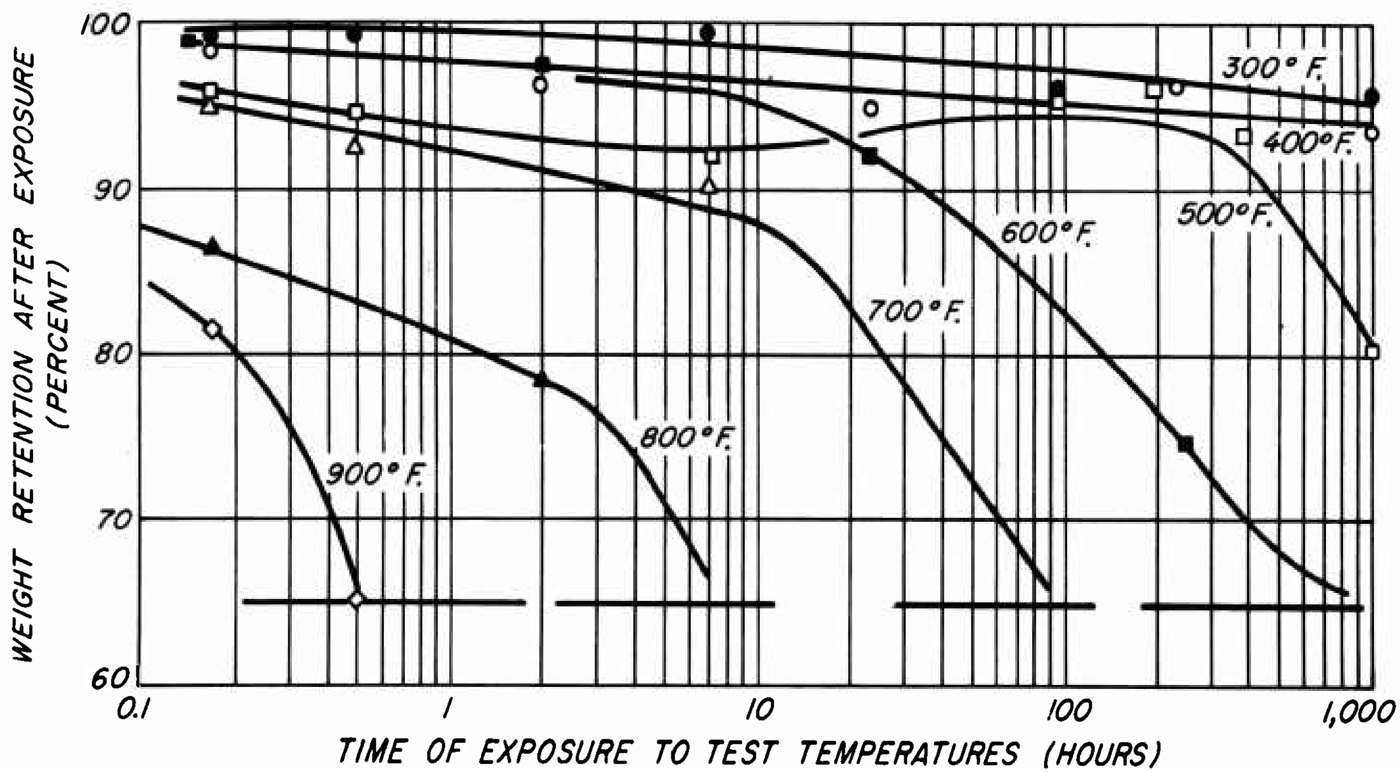

Figure 1.--Deterioration (as Weight Loss) at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

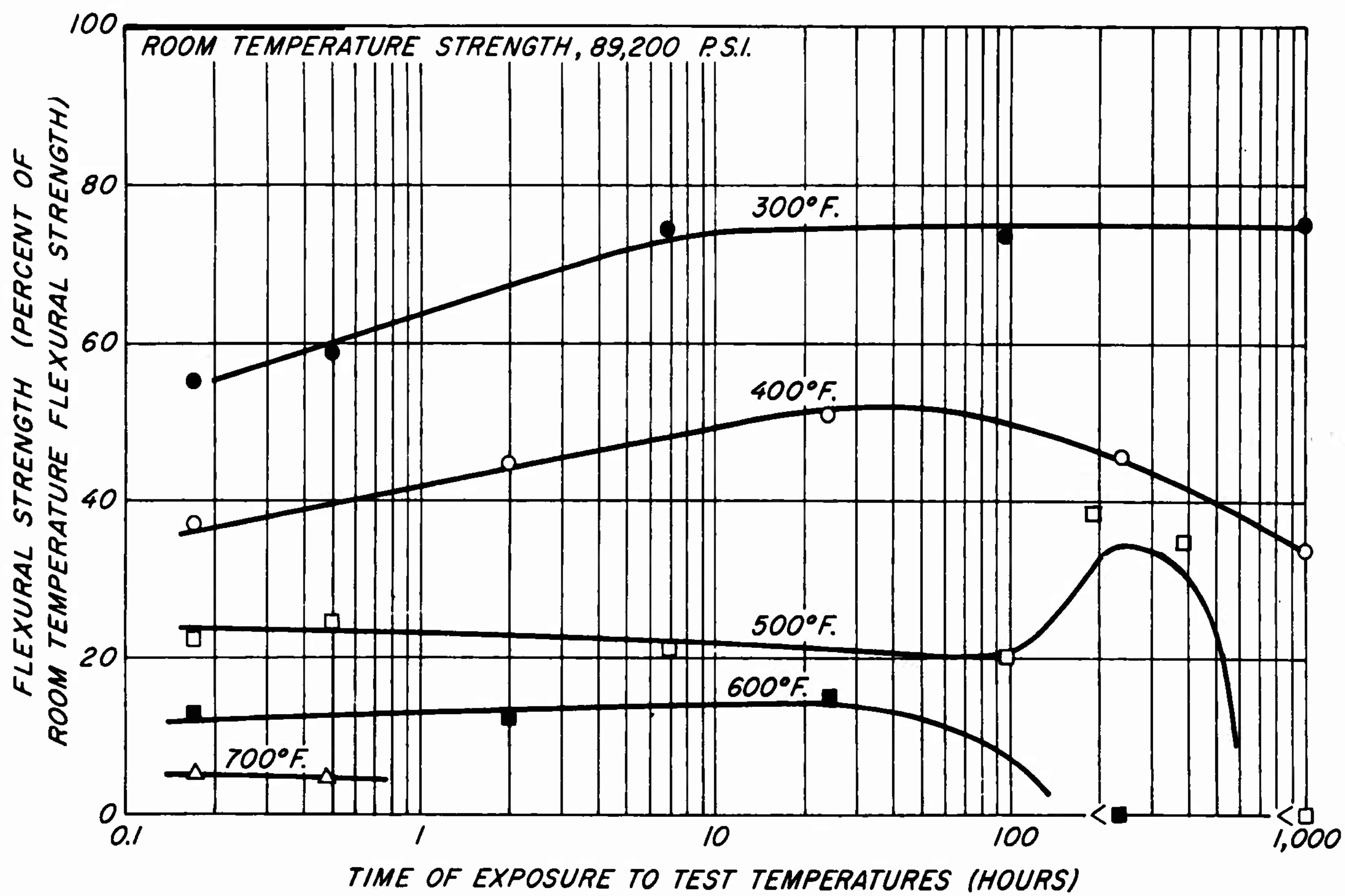

Figure 2. --Flexural Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

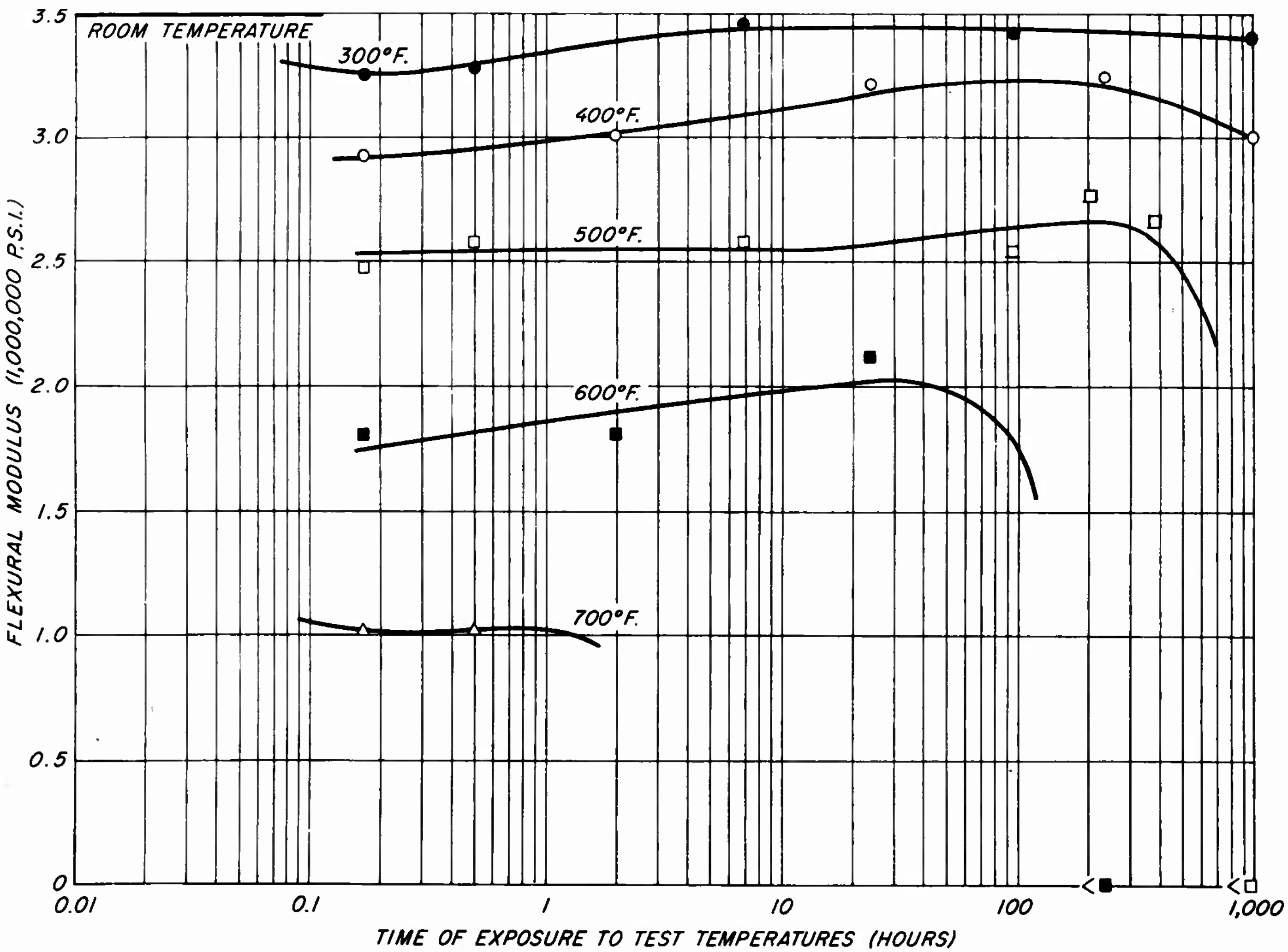

Figure 3. --Flexural Modulus at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

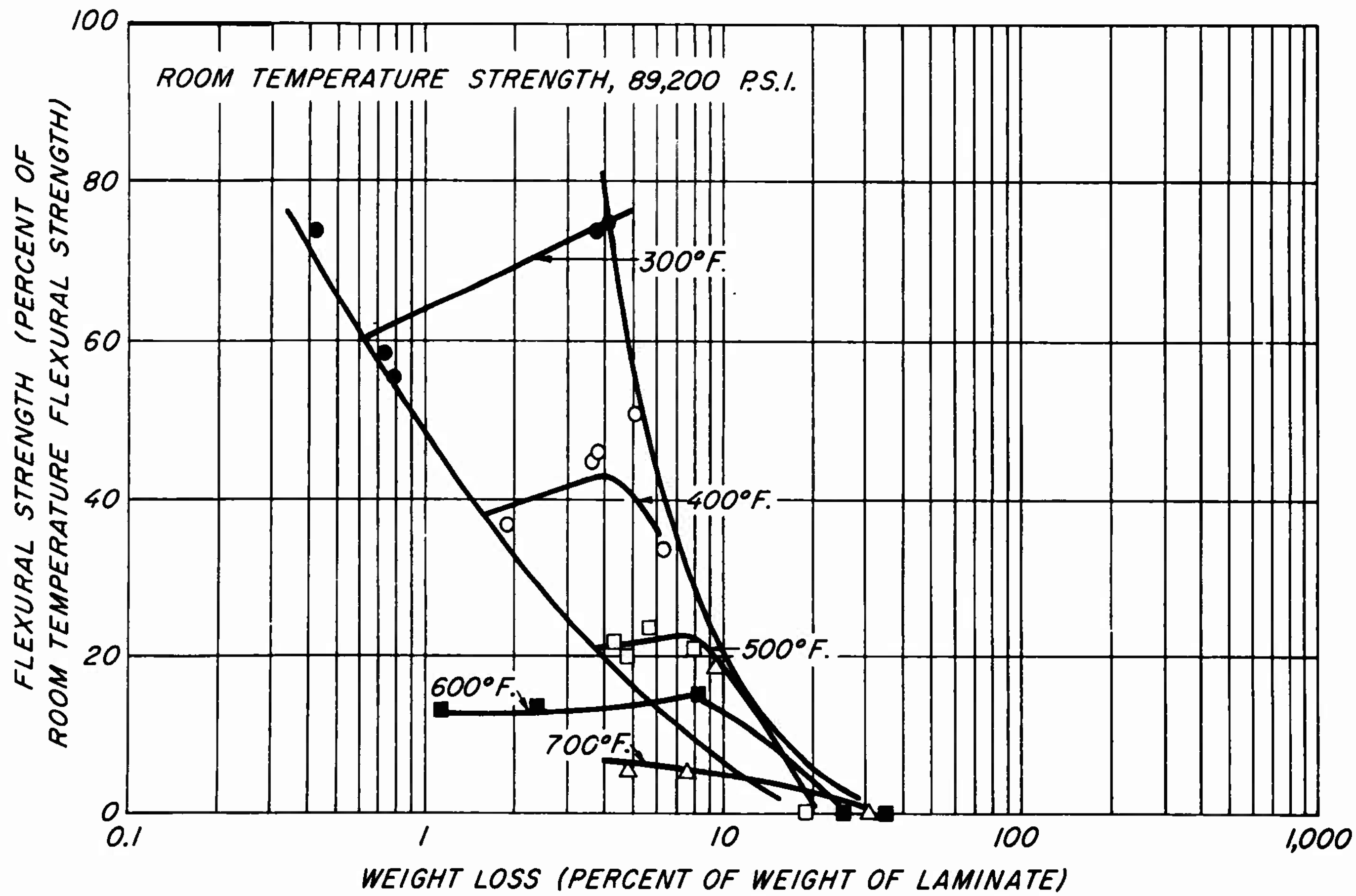

Figure 4. --Flexural Strength Versus Weight Loss at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

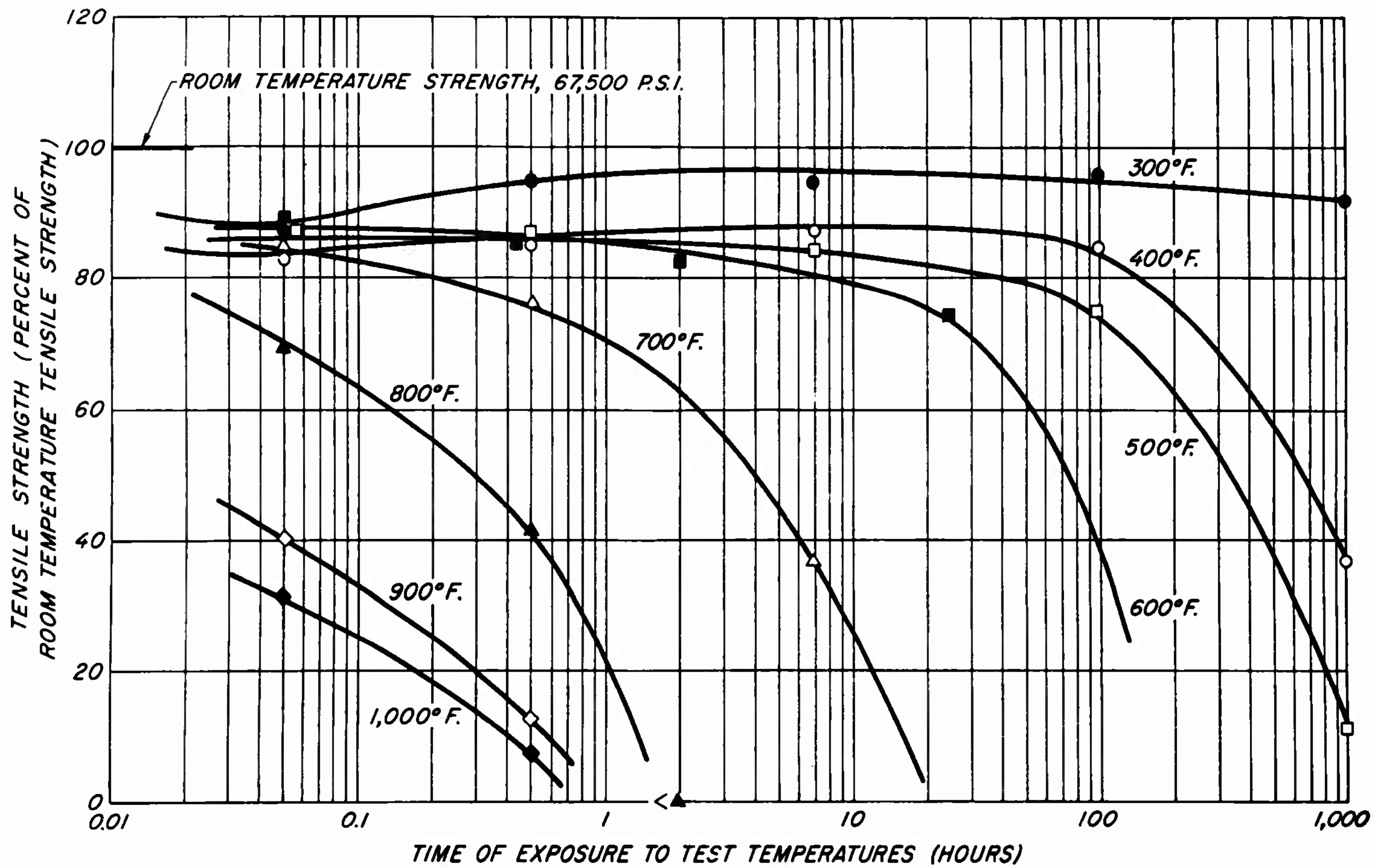

Figure 5.--Tensile Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric. Tests Made Parallel to Warp Direction.

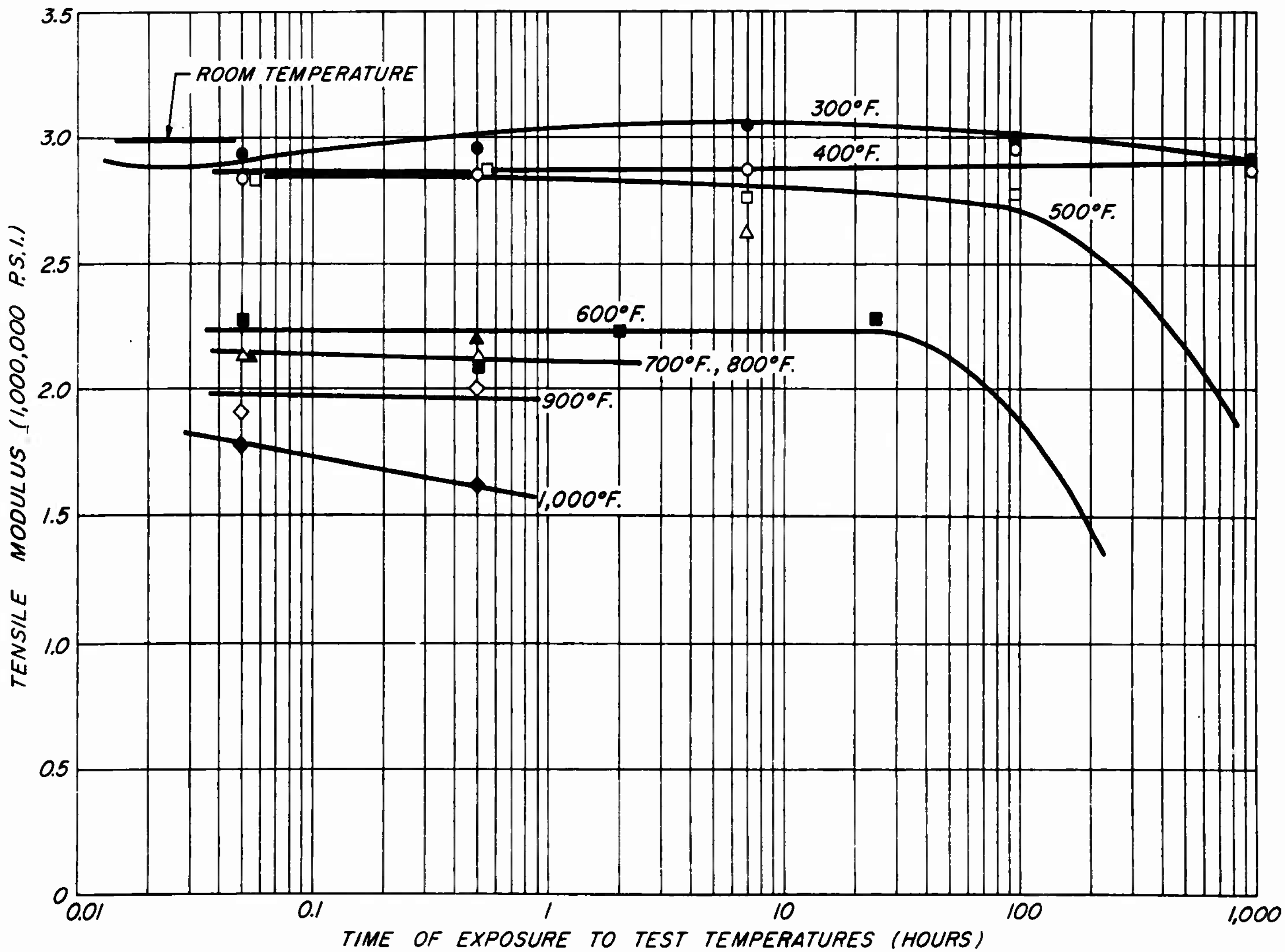

Figure 6.--Tensile Modulus at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric. Tests Made Parallel to Warp Direction.

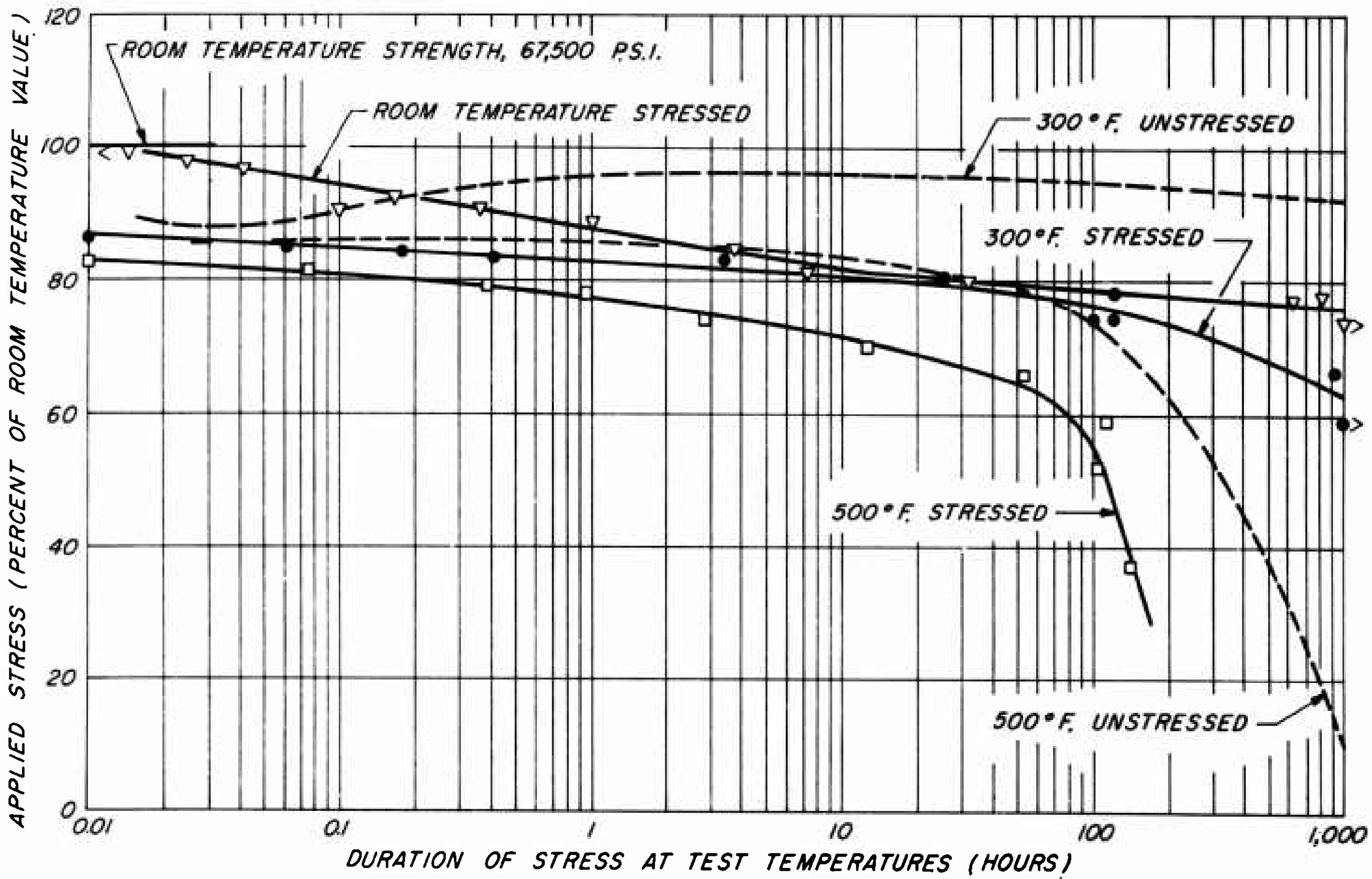

Figure 7. --Tensile Stress-Rupture Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric. Tests Made Parallel to Warp Direction.

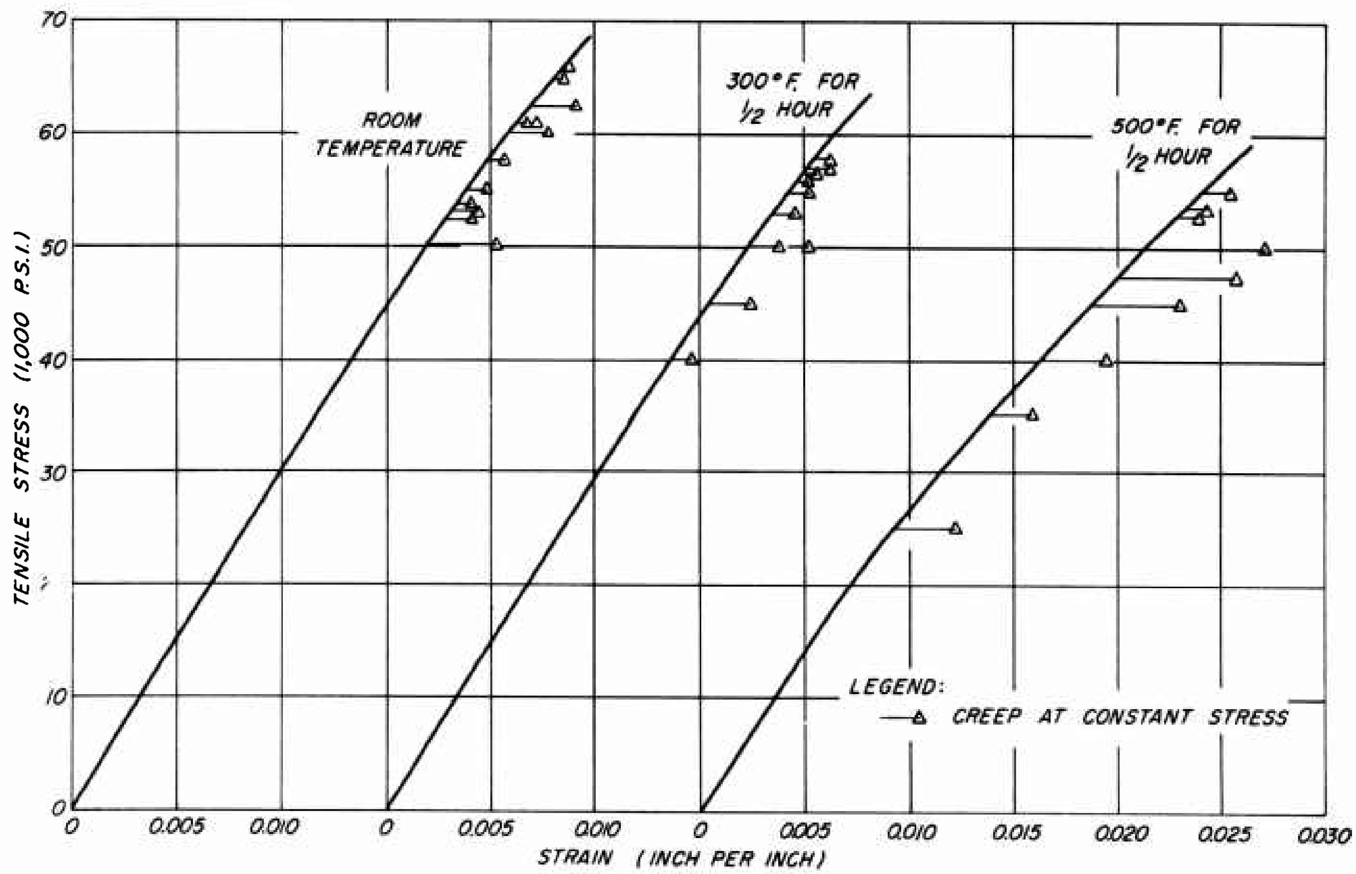

Figure 8. --Relationship of Tensile Creep at Various Stress Levels to Average Tensile Stress-Strain Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

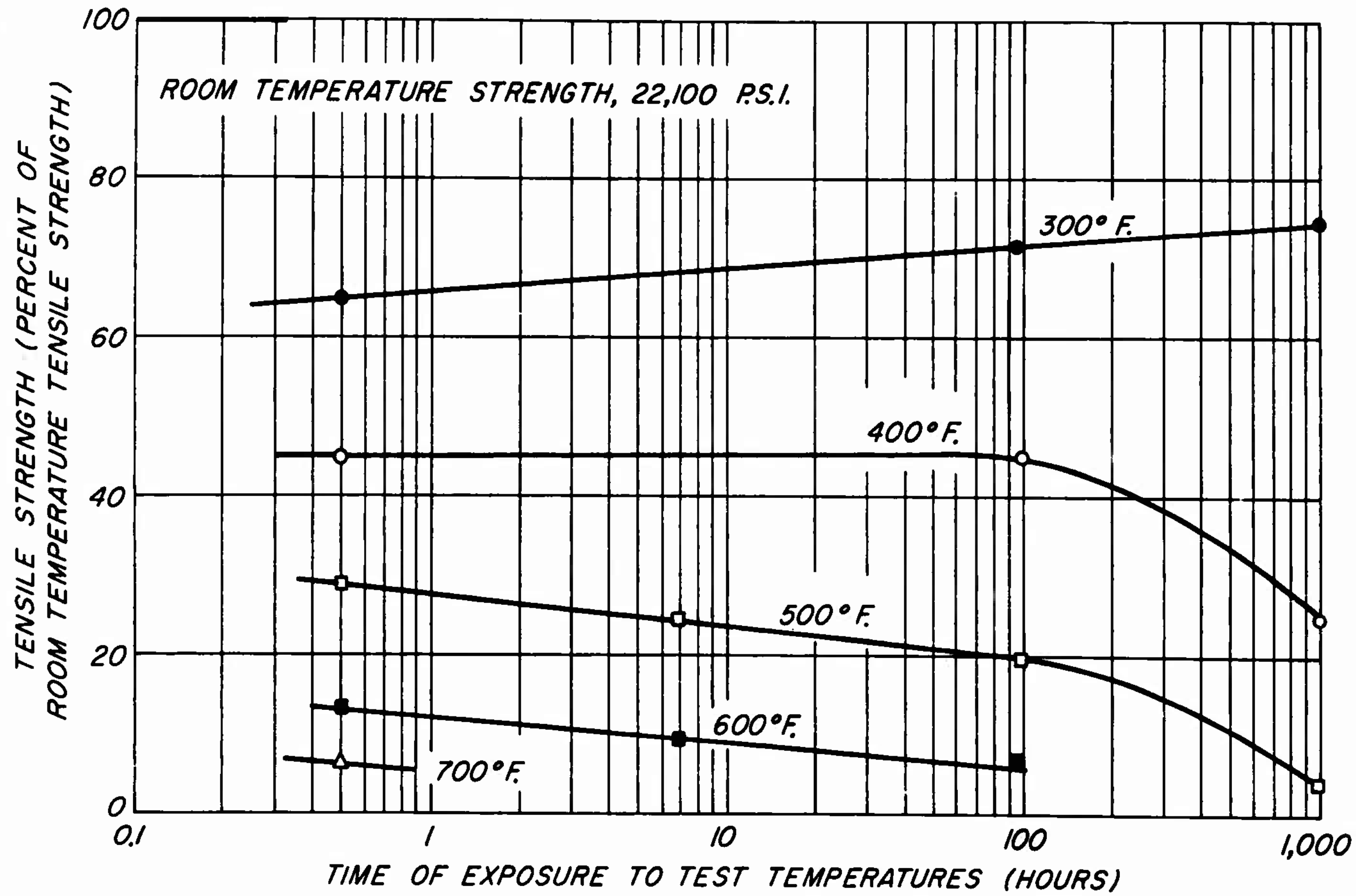

Figure 9.--Tensile Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric. Tests Made at 45° to the Warp Direction.

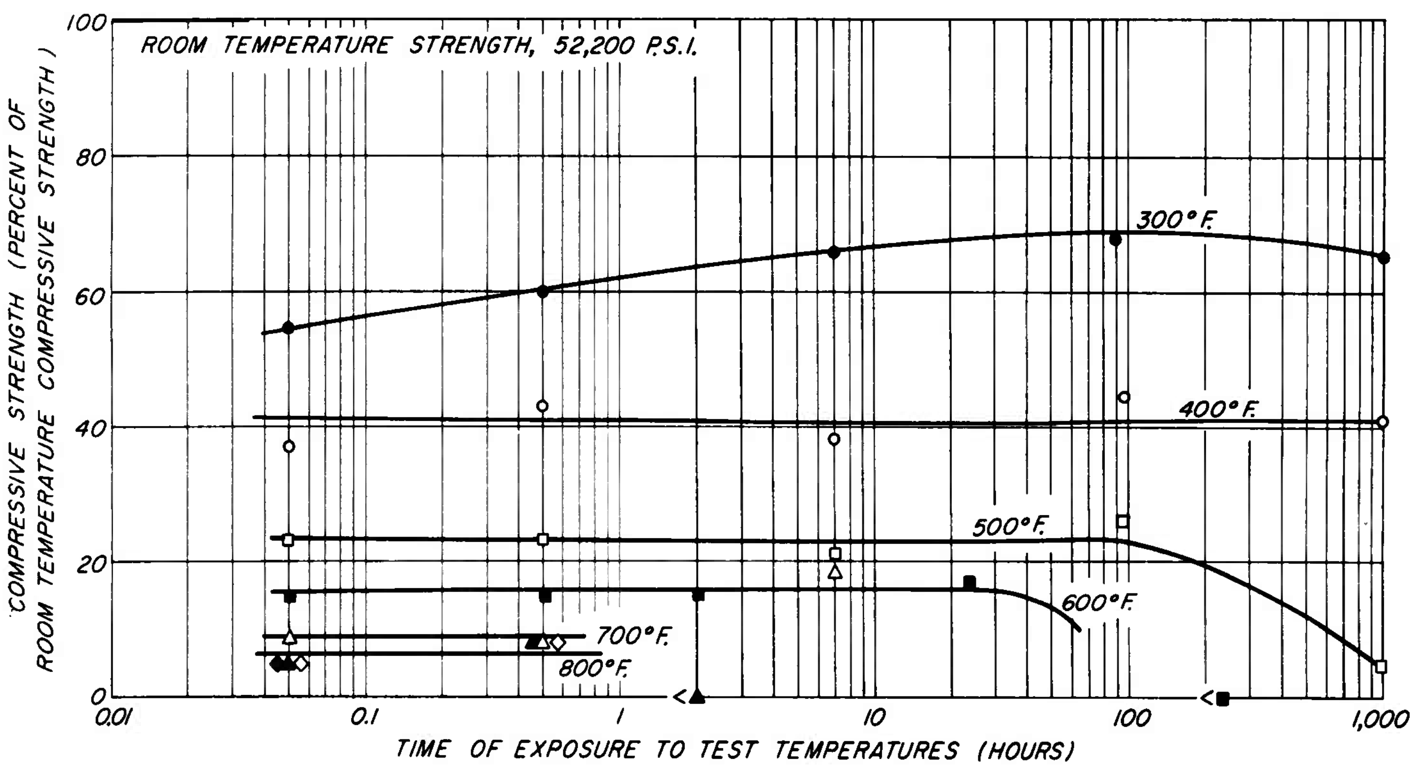

Figure 10. --Compressive Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

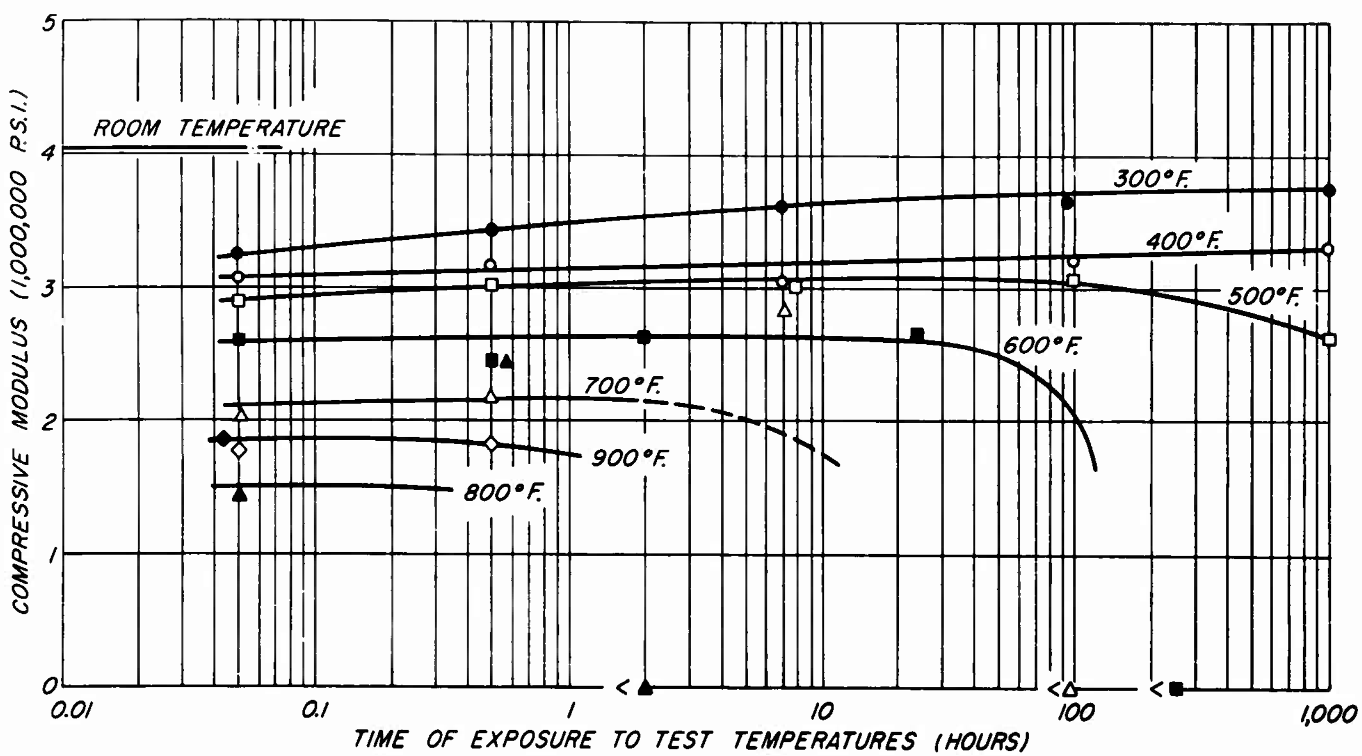

Figure 11. --Compressive Modulus of Elasticity at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

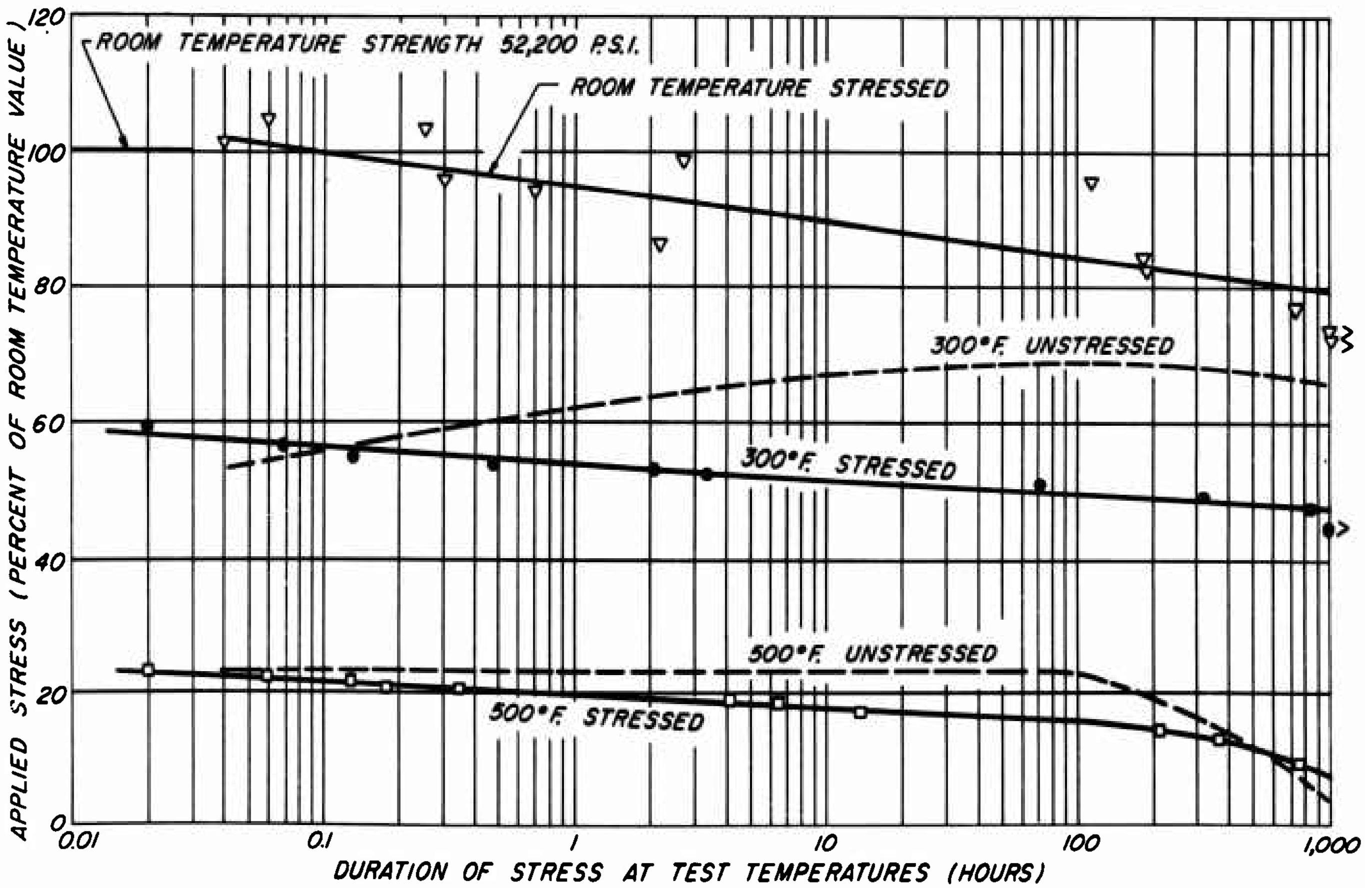

Figure 12. --Compressive Stress-Rupture Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

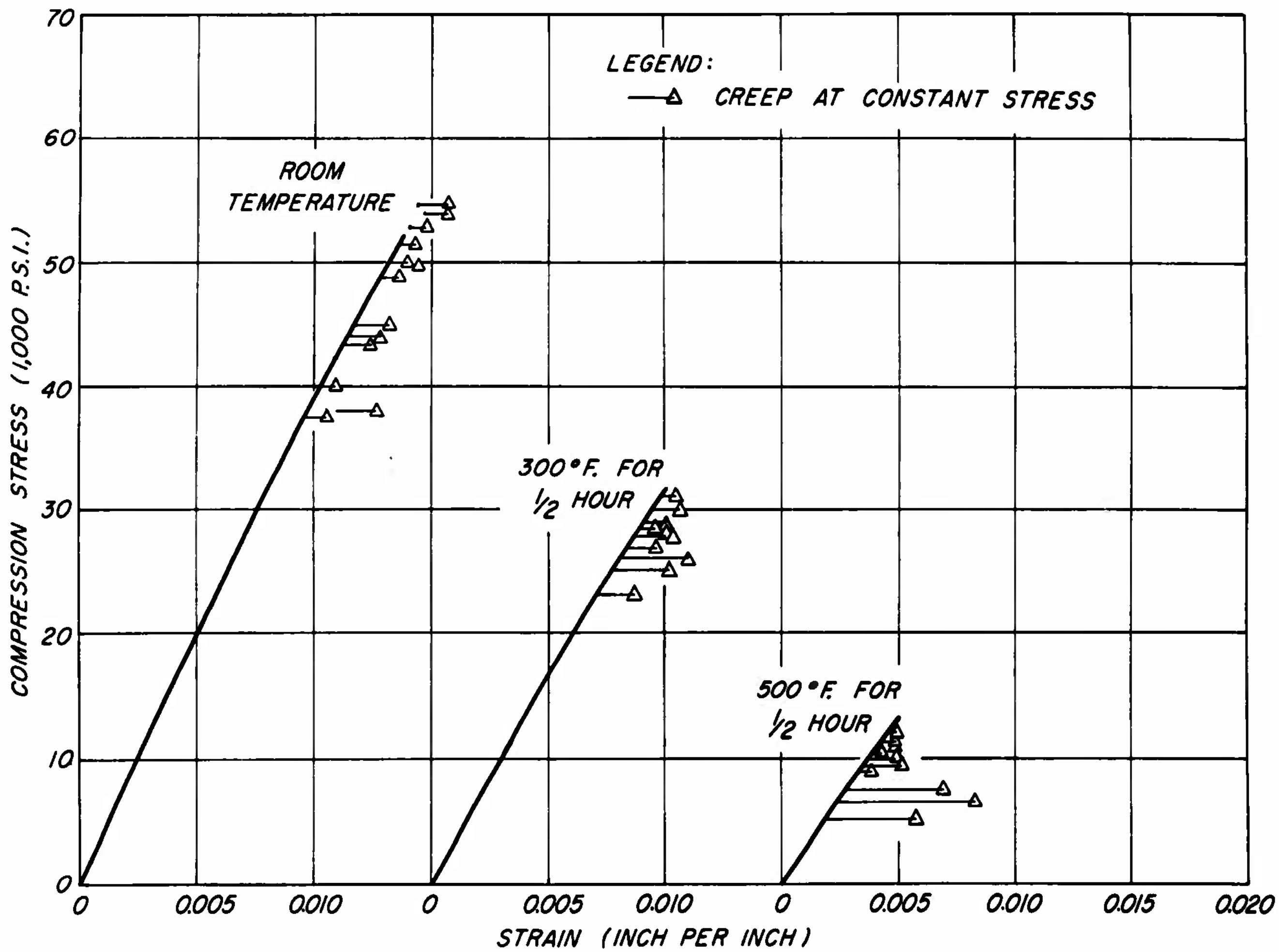

Figure 13. --Relationship of Compressive Creep at Various Stress Levels to Average Compressive Stress-Strain Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

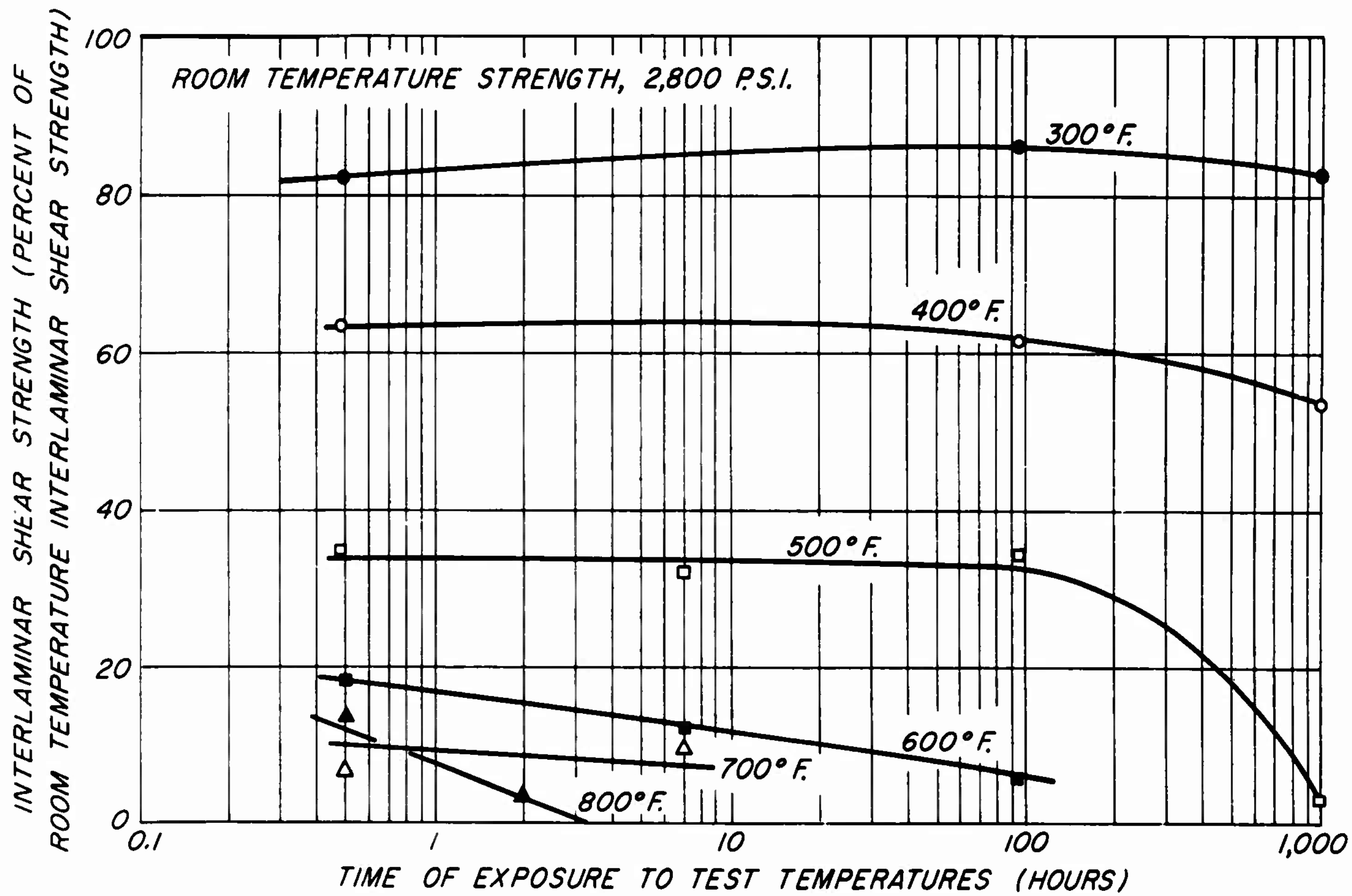

Figure 14. --Interlaminar Shear Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

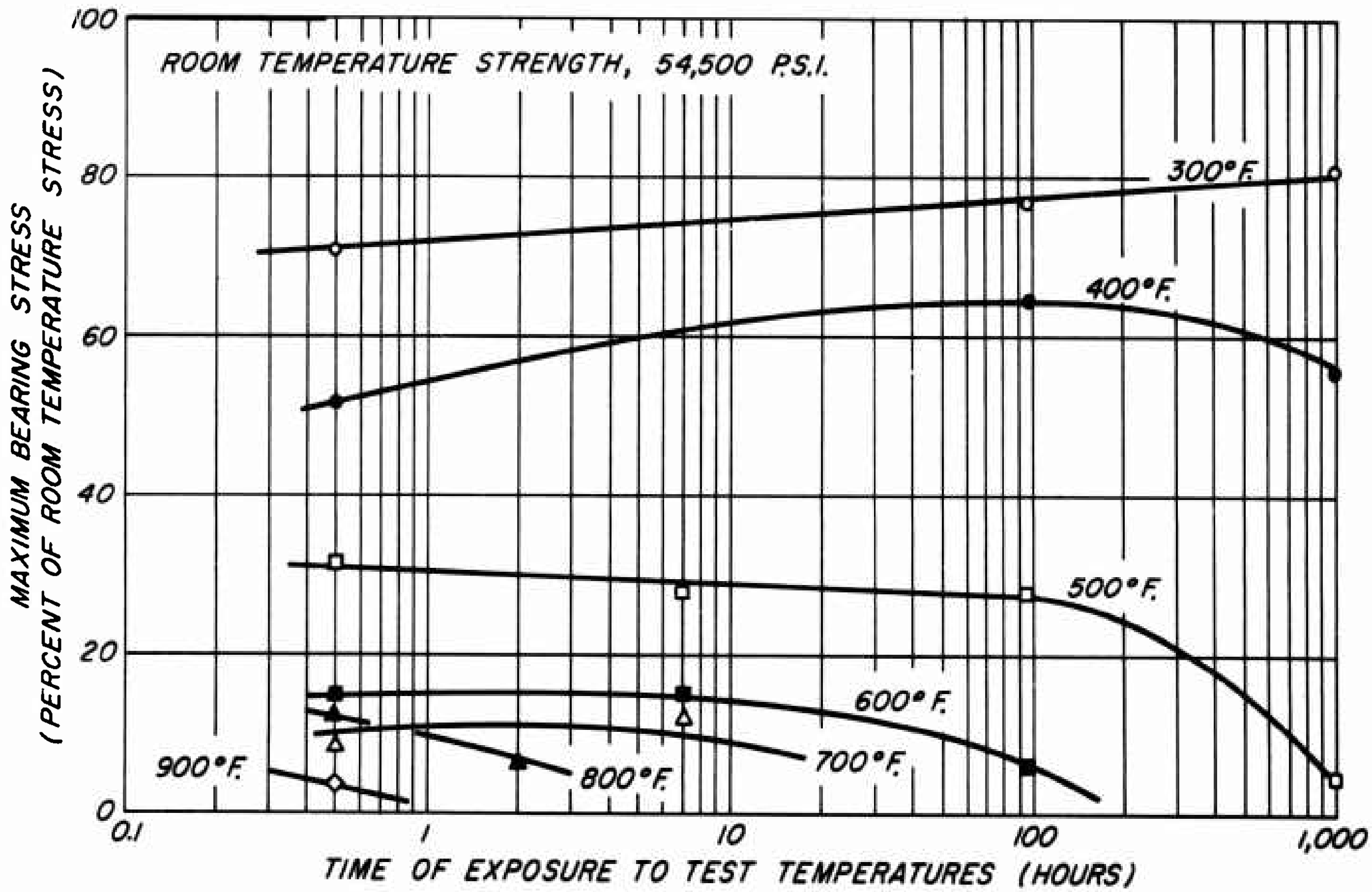

Figure 15. --Maximum Bearing Stress at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

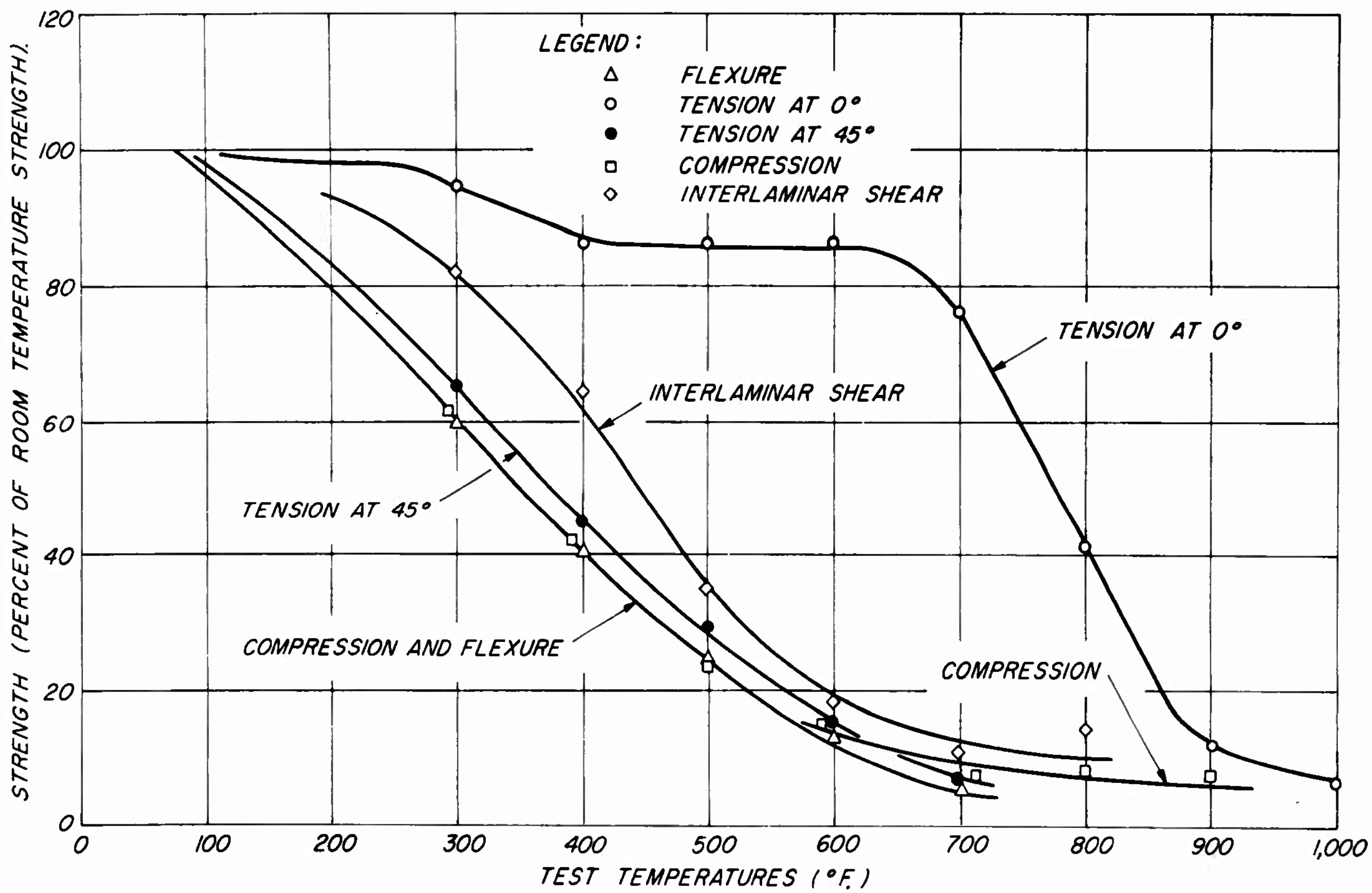

Figure 16.--Mechanical Strengths at Elevated Temperatures After 1/2-Hour Exposure for Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

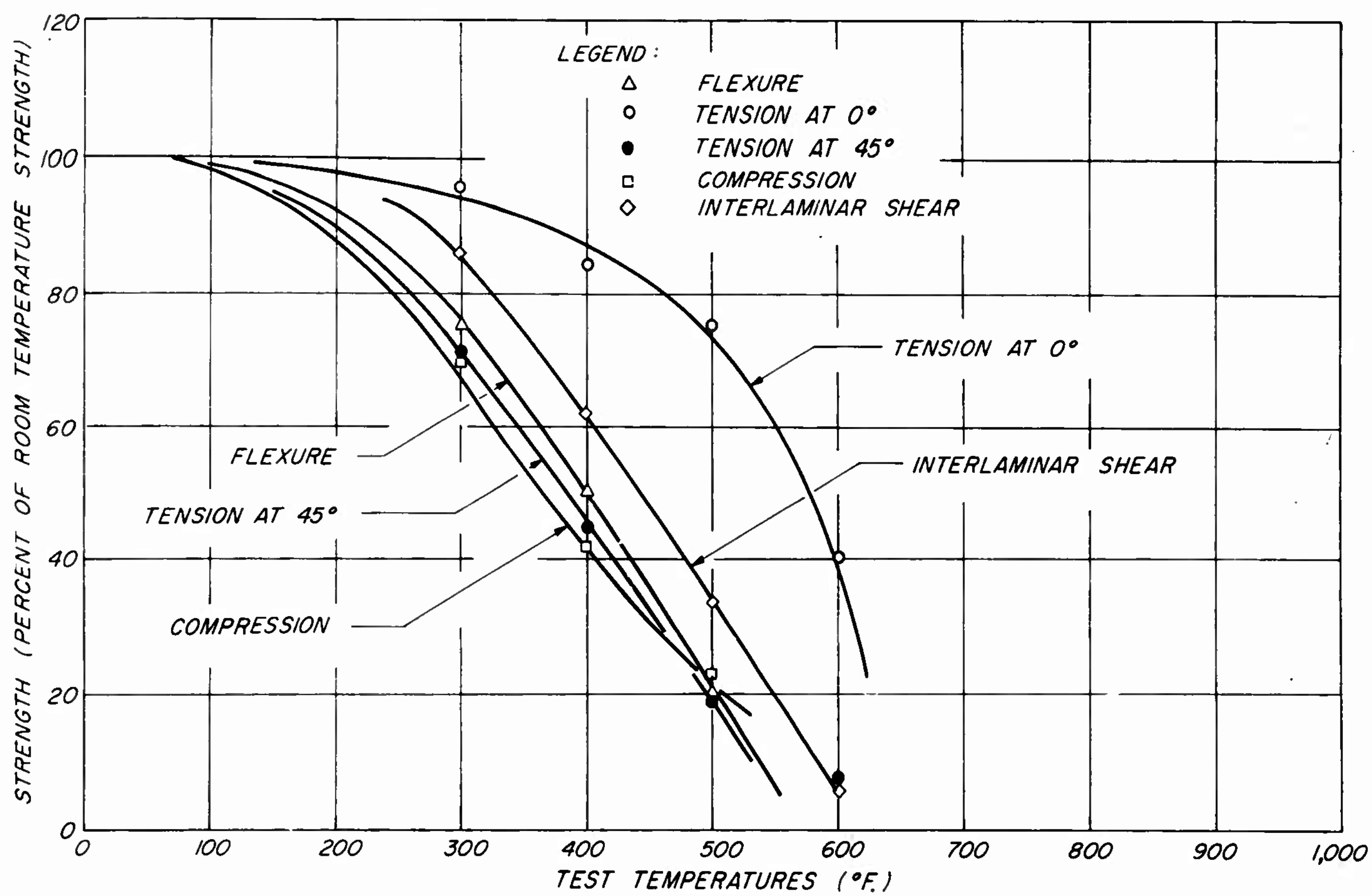

Figure 17.--Mechanical Strengths at Elevated Temperatures After 100-Hour Exposure for Epoxy Laminates Made of ERSB-0111 Resin and 181-A1100 Glass Fabric.

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